On the Variability of "Dynamic Seedability" as a Function of Time and Location over South Florida. Part II. Temporal Variability

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ABSTRACT

Using the one-dimensional cumulus model developed by Cotton, predictions of the effects of seeding cumulus clouds were performed during the month of July 1973 as part of the Experimental Meteorology Laboratory's Florida Area Cumulus Experiment 1973 experiment. In Part I we compared seedability predictions with the Miami 1200 GMT soundings and soundings taken over the center of the experimental area (Central Site) at 1400 GMT. It was found that substantial differences between the two predictions occurred on a number of days in spite of the fact that the soundings are separated in time by only 2 h and in space by only 110 km.

In this paper we compare seedability predictions with the MIA 1200 GMT soundings and the CS 1800 GMT soundings. The CS 1800 GMT soundings were assumed to be representative of conditions over the experimental area during the period of operation of the experiment. We found that the predictions with the MIA 1200 GMT soundings were, on the average, more representative of conditions over the center of the experimental area during the period of operation of the experiment than were the predictions with the CS 1400 GMT soundings. The results of this study indicate that the choice of a sounding site and sounding time to be used for prediction of seeding effects over an experimental area must be carefully considered in the design of the experiment.

1. Introduction

One of the difficulties in conducting a weather modification experiment is that it is often technically inconvenient or economically unfeasible to obtain atmospheric soundings near in time and in space to the actual operation of the experiment. The data obtained from such soundings are often used to predict the effects of seeding cumulus clouds (or "seedability") in the experimental area. The "seedability" then forms the basis for deciding if the day is appropriate for seeding. The question of the representativeness of the soundings available to the experimenter is, therefore, an important one. In Part I of this report (Cotton and Boulanger, 1975), we considered the effects of spatial variability of atmospheric soundings over South Florida on the daily decision process. In this paper we shall consider the combined effects of spatial and temporal variability of atmospheric soundings on predictions of "dynamic seedability."

"Seedability" was calculated using soundings taken over Miami and special soundings taken over the center of the experimental area. In the past, EML personnel determined if the day was suitable for seeding from an analysis of seedability calculations performed mainly with the Miami 1200 soundings (all times GMT). Occasionally this analysis was supplemented with the Tampa 1200 sounding and, when available, the Miami 1800 sounding.

The purpose of this paper is to determine the representativeness of the seedabilities predicted with the Miami 1200 soundings of conditions in the target area during the period of experimentation. The special soundings taken at 1800 over the center of the experimental area are considered to be most representative.

2. Description of the seedability model

The model used for predicting "dynamic seedability" is the one-dimensional entrainment model developed by Cotton (1972). The modifications that have been made to the model in order to predict seedability are discussed in Cotton and Boulanger (1975). Seedability is defined as the difference in cloud top height predicted by the model for a natural cloud [assuming that natural nucleation obeys the Fletcher (1962) exponential ice nuclei equation] and a seeded cloud (assuming that 5.5×10^4 crystals per liter are nucleated between -4 and -7°C). Seedability was predicted for a spectrum of cloud radii of 0.5, 0.75, 1.0, 1.25, 1.5 and 2.0 km. Throughout this study the cloud base height is assumed to be constant at 915 m MSL which was found to be representative for the central portion of the South Florida peninsula during the summer months.

3. Results of numerical experimentation

Seedability calculations were performed for the month of July 1973, using the Miami 1200 GMT soundings

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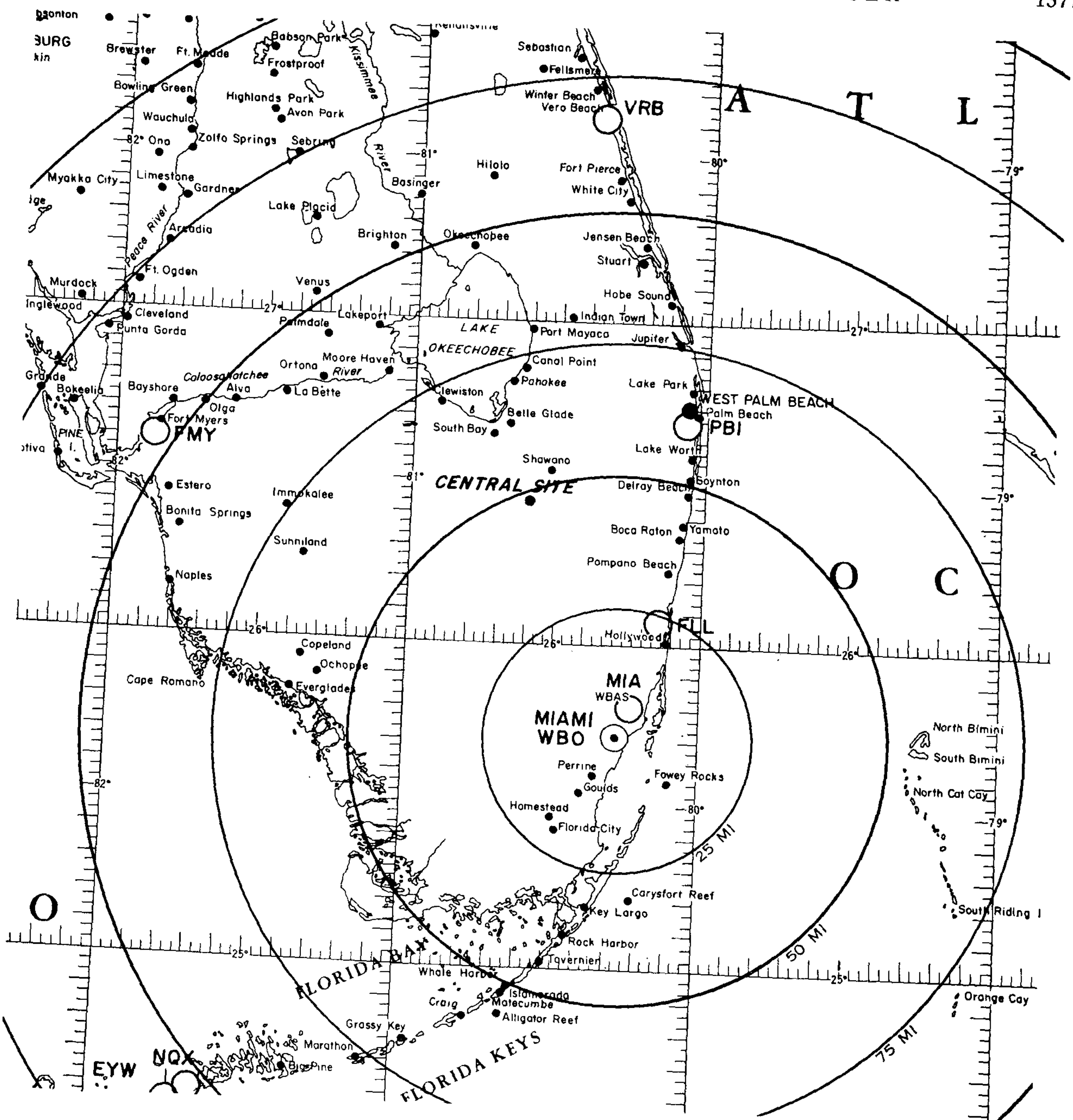

Fig. 1. Map of South Florida illustrating the location of the Miami and Central Site radiosonde stations.

and the Central Site 1800 GMT soundings. Fig. 1 illustrates the locations of the Miami and Central Site stations. In Part 1 of this paper we compared seedability predictions using the Miami 1200 and Central Site 1400 soundings. It was found that substantial differences between the two seedability predictions occurred on a number of days in spite of the fact that the soundings were separated in time by only 2 h and in space by only 110 km. It was suggested that the differences in seedability estimates for the two soundings were a consequence of the more frequent intrusion of dry air masses of varying height and thickness over the more northerly Central Site location.

Fig. 2a illustrates the predicted effects of seeding using the Miami (MIA) 1200 and Central Site (CS) 1800 soundings for 29 July 1973. The model predicted the cloud radius at which the maximum effect would occur, to be 0.75 km for both the MIA and CS soundings. The differences between the two calculations were only of the order of 500 m, with the larger effect predicted using the MIA sounding. Fig. 2b illustrates the predicted effects of seeding using the MIA 1200 and

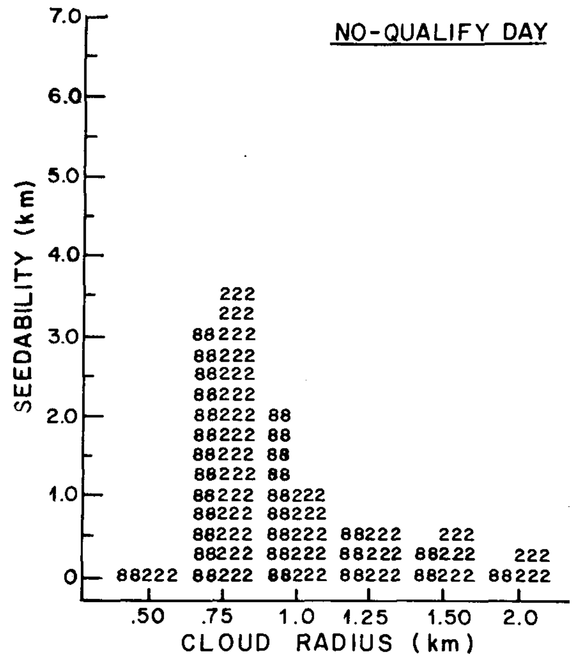

FIG. 2a. Predicted seedability spectrum for the MIA 1200 GMT sounding (222) and the CS 1800 GMT sounding (88) on 29 July 1973, a "NO-Qualify" day.

CS 1400 soundings for 29 July 1973. In contrast to both the results from the MIA and CS soundings, the prediction using the CS sounding indicated the maximum seeding effect would occur for clouds of 1.25 km radius. Furthermore, the magnitude of the maximum

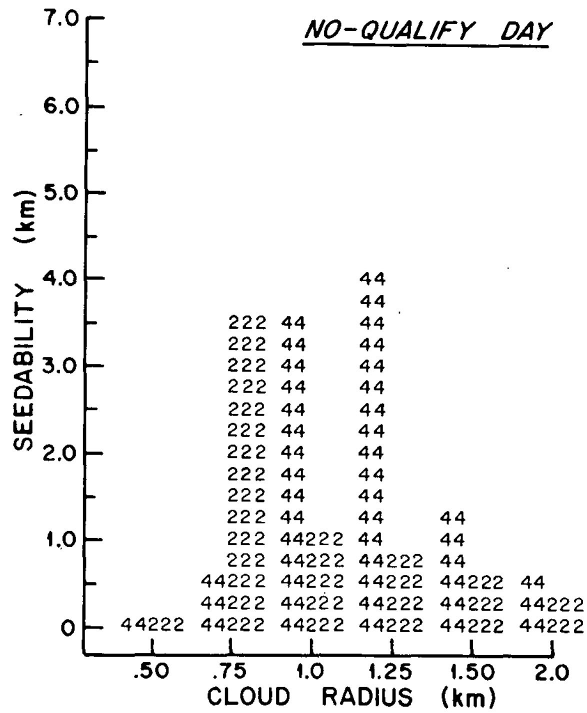

FIG. 2b. Predicted seedability spectrum for the MIA 1200 GMT sounding (222) and the CS 1400 GMT sounding (44) on 29 July 1973, a "NO-Qualify" day.

seeding effect predicted using the CS 1800 sounding was 500 m greater than that predicted using the MIA

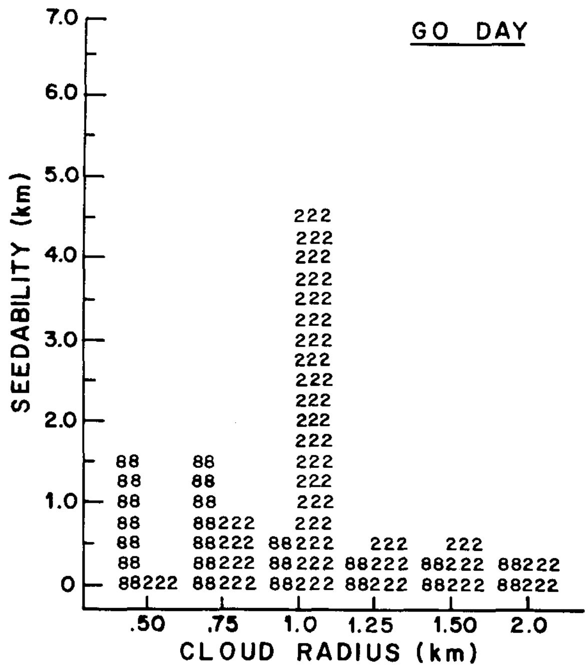

FIG. 3a. Predicted seedability spectrum for the MIA 1200 GMT sounding (222) and the CS 1800 GMT sounding (88) on 20 July 1973, a "GO" day.

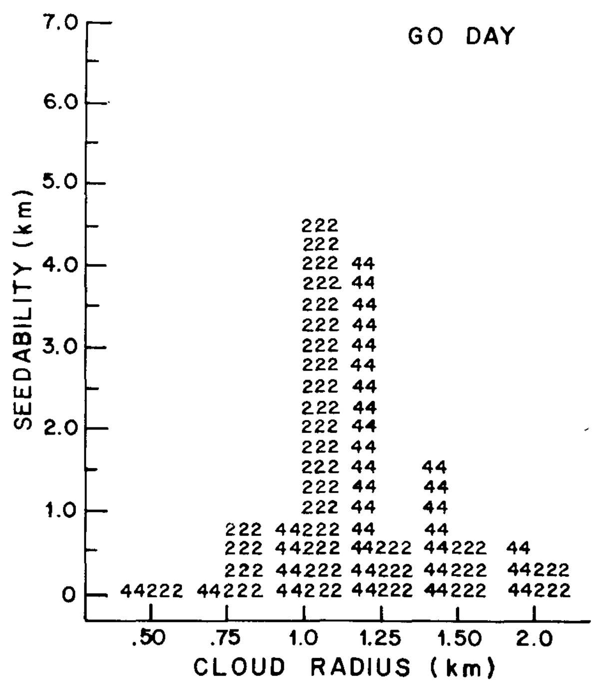

FIG. 3b. Predicted seedability spectrum for the MIA 1200 GMT sounding (222) and the CS 1400 GMT sounding (44) on 20 July 1973, a "GO" day.

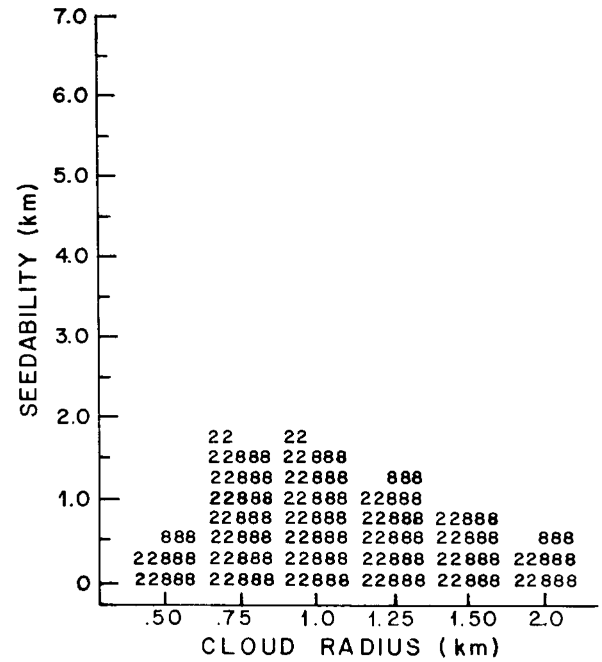

Fig. 4a. Average seedability spectrum for the CS 1800 GMT sounding (88) and MIA 1200 GMT sounding (222).

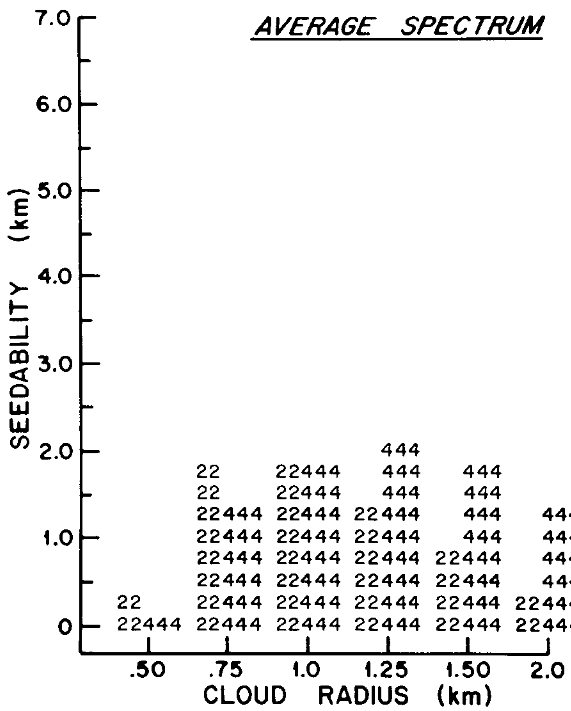

Fig. 4b. Average seedability spectrum for the CS 1400 GMT sounding (44) and MIA 1200 GMT sounding (222).

1200 sounding and 1000 m greater than that using the CS 1400 sounding.

On 20 July 1973 even greater differences in the predicted "seedabilities" for the three soundings were found. Fig. 3a illustrates the predicted effects using the MIA 1200 and CS 1800 soundings on 20 July 1973. Using the MIA sounding, the model predicted a maximum "seedability" of 4.5 km for a cloud radius of 1.0 km. For the CS sounding, we found that the predicted maximum seedability was 1.5 km for clouds with radii of 0.5 to 0.75 km. As illustrated in Fig. 3b, the maximum effect predicted using the CS 1400 sounding was 4.0 km for clouds with radii of 1.25 km.

To illustrate that the large differences in predicted effects of seeding are not unique to these two days, the average effects were calculated for the month of July 1973. Fig. 4a illustrates the average predicted effects of seeding using for the MIA 1200 and CS 1800 soundings for July 1973. We see that the predicted radius of maximum "seedability" occurred, on the average, at 0.75 to 1.0 km for both the MIA and CS soundings. In addition, the amplitude of the maximum "seedability" differed by only 250 m, on the average, for predictions using the CS and MIA soundings. As illustrated in Fig. 4b, the predictions using the CS 1400 sounding resulted in an average cloud radius of 1.25 km at which the maximum seedability should occur and an amplitude of average maximum seedability which was over 500 m greater than the prediction using the CS 1800 sounding. The results show that the MIA 1200 sounding produced a prediction of the effect of seeding, on the average, which is in closer agreement to predictions over the center of the experimental area during the period of the experiment (predictions using the CS 1800 sounding) than did the predictions using the CS 1400 sounding.

To determine the reason for the differences in the predicted effects of seeding, let us look at the average soundings for the month of July 1973, for MIA 1200 GMT, CS 1400 GMT and CS 1800 GMT, as illustrated in Fig. 5. As noted in Part 1, the CS 1400 was, on the average, considerably drier than the MIA 1200 sounding. The observed dry layer caused the predicted vertical growth of clouds of small radii to be insufficient for the postulated effects of seeding to occur. In addition, the entrainment of dry air into the clouds which were large enough to penetrate into supercooled layers was predicted to retard the growth of nonseeded clouds, while the postulated added buoyancy from the seeding was predicted to increase the growth of seeded clouds and cause them to penetrate to considerable depth. As illustrated in Fig. 5, the average CS 1800 sounding had a moisture profile which was between the MIA 1200 and CS 1400 average sounding. To some degree, this fact explains why predictions using the MIA 1200 sounding were more nearly comparable to the predictions using the CS 1800 sounding than were the predictions using the CS 1400 sounding.

An examination of the 20 July 1973 soundings shown in Fig. 6 illustrates the moistening of the convective

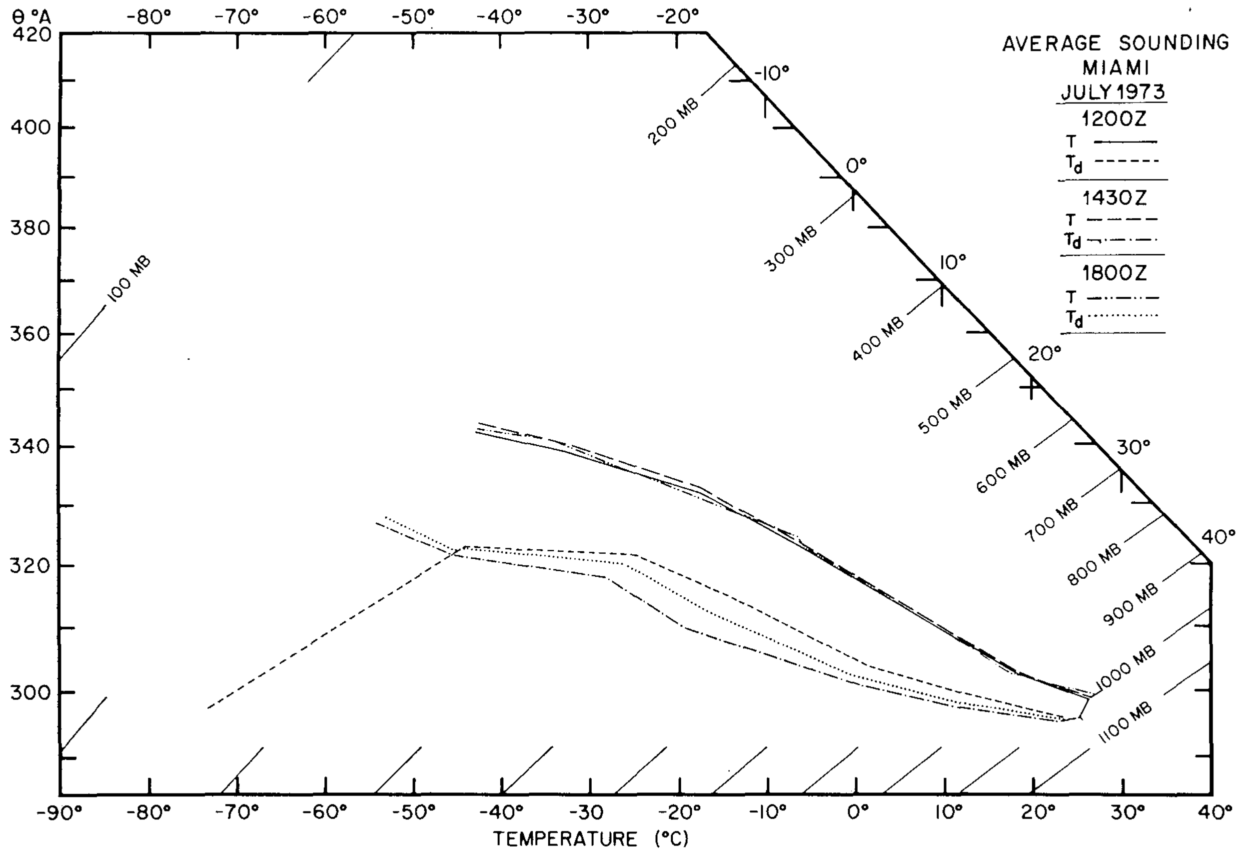

FIG. 5. Average MIA 1200 GMT, CS 1400 GMT and CS 1800 GMT soundings for month of July 1973.

layer from 1400 to 1800 GMT. The moistening of the layer was probably due to moisture transport by convection. In addition, heating of the convective layer had also destabilized the temperature field; both of these factors contributed to the reduction in the predicted effects of seeding from 1400 to 1800 as shown in Figs. 3a and 3b.

While, in general, an increase in the moisture content and a destabilization of the convective layer lead to a shift to smaller cloud radii in the radius at which maximum seedability was predicted to occur and a decrease in the amplitude of the maximum seedability, on a few days during the month of July a reverse behavior was noted. Figs. 7a and 7b illustrate a comparison of the effects of seeding predicted using the MIA 1200, CS 1800 and CS 1400 soundings for 27 July 1973. Fig. 7a shows that a maximum seedability of over 5.5 km at a cloud radius of 1.5 km was predicted using the CS 1800 sounding, while the prediction using the MIA 1200 sounding resulted in a negligible prediction of "seedability." Fig. 7b shows that a maximum seedability of 2.5 km at a radius of 1.25 km was predicted using the CS 1400 sounding. The reason for such significant differences between the predictions on this day was quite evident from the synoptic analysis. On 27 July 1973, the ridge over South Florida was migrating southward, resulting in a change in the basic flow from an easterly flow regime to a westerly flow. Thus, instead of the more normal moistening of the lower troposphere over the experimental area as the day progressed, a drying out of the layer took place as the drier westerly air mass migrated southward over the target area. The drying out, in turn, led to a prediction with the CS 1400 sounding which was more representative of the prediction with the CS 1800 sounding than the MIA 1200 sounding.

4. Summary and conclusions

An analysis of the spatial and temporal variability of dynamic seedability over South Florida was reported in this paper. In Part 1 (Cotton and Boulanger, 1975) we found that the spatial variation in atmospheric soundings over distances of only 150 km (as exhibited by the MIA 1200 and CS 1400 coundings) can result in substantial differences between "seedability" predictions.

In this paper, we found that predictions of the MIA 1200 soundings were, on the average, in closer agreement with the predictions using the CS 1800 sounding than were the predictions using the CS 1400 sounding. To some degree, the better agreement between the predictions using the MIA 1200 and the CS 1800 soundings than the agreement between the predictions using the MIA 1200 and CS 1400 soundings is fortuitous.

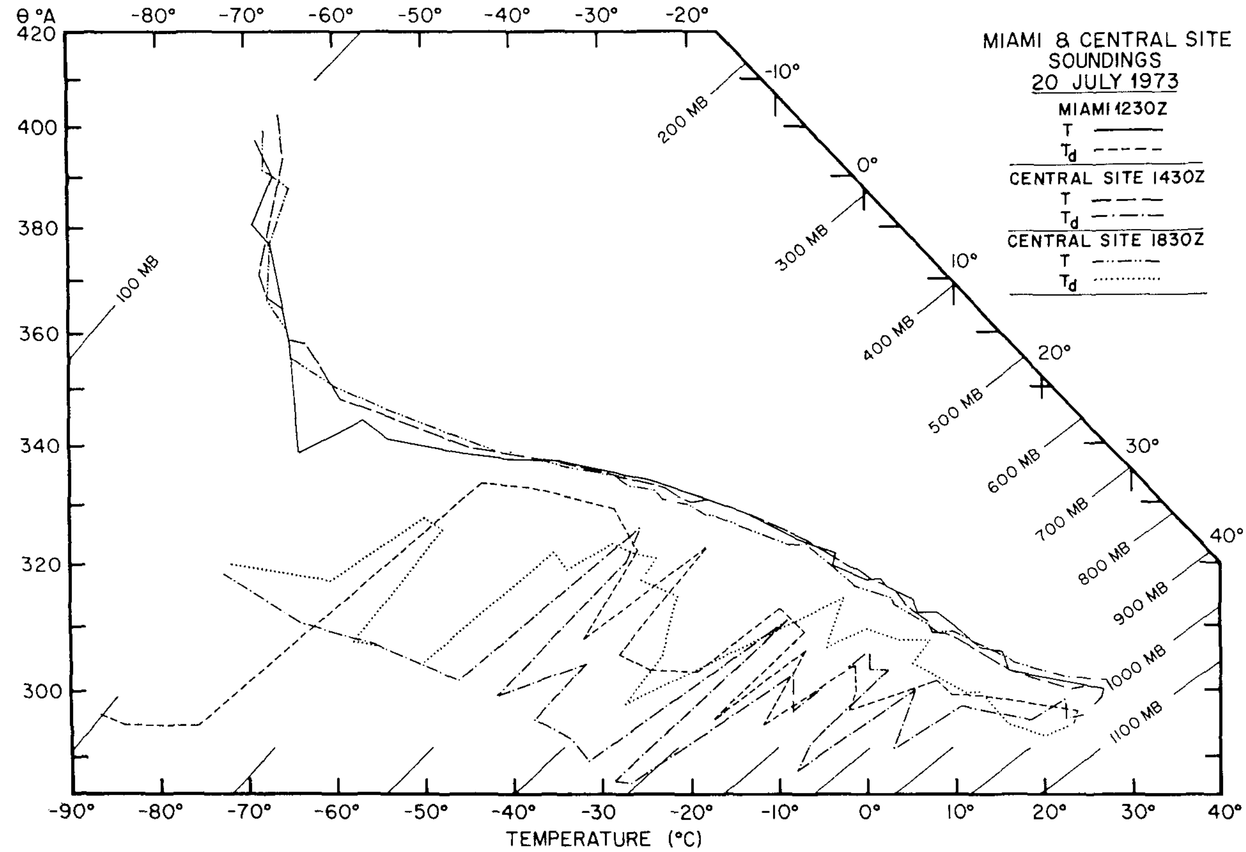

FIG. 6. Soundings for MIA 1200 GMT, CS 1400 GMT and CS 1800 GMT on 20 July 1973.

One might argue, for example, that under southeasterly flow Miami is upwind of the experimental area and therefore more representative of conditions that might prevail during the afternoon as the air mass is advected northward from Miami. In actual fact, only one out of six days in which the predicted seeding effect using the MIA 1200 sounding was similar to the prediction using the CS 1800 sounding, was the flow out of the southeast. The flows on the remainder of the days were southwesterly and westerly. Thus, it appears that the air over the Central Site became moistened during the day by locally generated convection and not by virtue of being downwind of Miami. The effect of the local moistening and thermal destabilization modified the Central site sounding. At 1400 GMT the Central site sounding exhibited a moisture structure in the 400 to 600 mb levels characteristic of a different air mass than the air mass over Miami at 1200 GMT. Hence the predicted effects of seeding using the diurnally modified CS 1800 sounding were more comparable to those predicted with the MIA 1200 sounding.

Such a diurnal modification of the Central site sounding did not always occur, however. On 27 July 1973, for example, the predicted seedability using the MIA 1200 sounding was negligible, while those predicted with the CS 1400 and 1800 soundings were quite significant. On this particular day, the ridge over South Florida receded, thus bringing the drier, westerly air mass (observed from the CS 1400 sounding) deeper over the Central site.

Thus, it is clear that the choice of a sounding site and sounding time to be used for prediction of seeding effects over an experimental area must be carefully considered in the design of the experiment. To make optimum use of the experimental facilities, it is desirable to have soundings as near in time and space to the time and location of the actual experiment and, in addition, the capability to perform real-time analyses of the soundings, such as the predictions of seedability discussed above. The availability of such soundings is also extremely valuable in the post analysis of the experiment.

A few words of caution should be mentioned. When interpreting the predicted effects of seeding discussed in preceding sections, one should realize that these results represent the relative potential of dynamic seedability given the existence of clouds having the radii specified in the calculations. The model does not predict that such clouds will be present on any given day over the experimental area. In a moist, semitropical environment such as South Florida, clouds of the size range specified above often form over an ex-

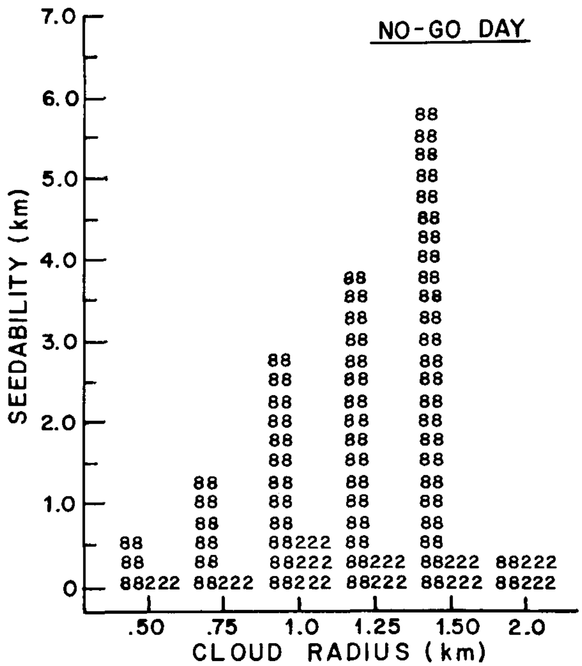

FIG. 7a. Predicted seedability spectrum for the MIA 1200 GMT sounding (222) and the CS 1800 GMT sounding (88) on 27 July 1973, a "NO-GO" day.

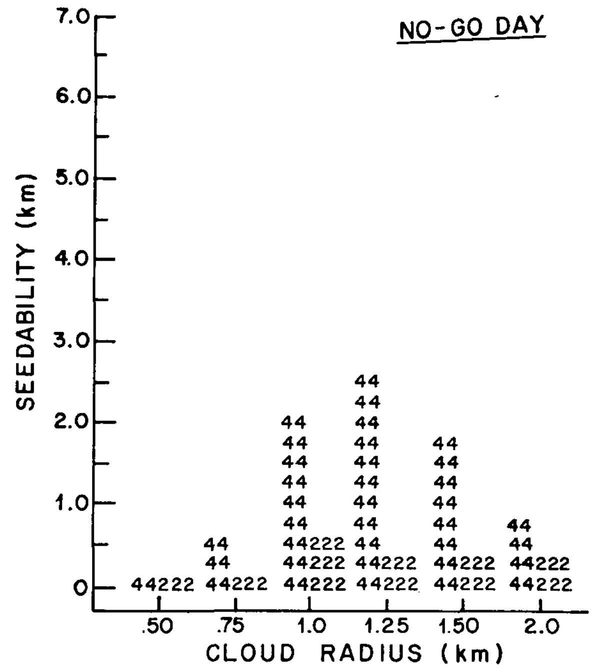

FIG. 7b. Predicted seedability spectrum for the MIA 1200 GMT sounding (222) and the CS 1400 GMT sounding (44) on 27 July 1973, a "NO-GO" day.

tensive portion of the day. It is not, however, uncommon to find a day over South Florida during the summer when large seedabilities are predicted by the model, yet the intrusion of upper-level cirrus may cut off surface heating and prevent the formation of the type of clouds predicted to have the greatest potential for cloud growth from seeding.

Considering the physical and dynamic limitations of the model (see Cotton, 1975) one should not interpret the magnitude of seedability for a given cloud too literally. It is not likely that every, or perhaps any, cloud having a radius equivalent to the radius at which maximum seedability was predicted, will respond with an enhanced vertical growth equivalent to the maximum predicted growth when seeded. Instead, the model predictions should be interpreted as the relative potential for modification of cloud dynamics for a given atmospheric sounding. The actual realization of such a potential will depend on 1) the formation of a broad size range of dynamically active cumuli in which natural glaciation is suppressed during the active growth stages and 2) on the experimenter's judicious selection of those clouds which have the greatest potential for modification.

The criteria for cloud selection at this time is quite subjective. The experimenter generally looks for a cloud which has penetrated the −10°C isotherm level and which has a visibly firm top (so called "hard" top appearance), well-defined cloud base, and if the cloud is actually penetrated, high values of supercooled liquid water content and large updraft velocities.

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